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Development of 16 kWh power storage system applying Li-ion batteries

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Abstract

A 16 kWh power storage system applying Li-ion batteries has been jointly developed by Kyushu Electric and Mitsubishi Heavy Industries. The system comprises a Li-ion battery pack, an inverter and a battery protection system. Four cells, each with a capacity of 270 Wh, are connected in a series to form a single 1.1 kWh module battery. The Li-ion battery pack is made up of a series of 15 such module batteries. A 270 Wh cell, in which Li–manganese oxide is used for the cathode and graphite for the anode, can expect to perform 3500 lifecycles during operating conditions of the rated 70% DOD. Even though power loss in the inverter and battery protection system must be further reduced, satisfactory response was found both in the batteries and inverter control, leading to the creation of a practical power storage system applying Li-ion batteries.

Keywords: Power storage system; Li battery; Manganese oxide

1. Introduction

Recent power demand in Japan is characterized by a growing difference of demand between seasons, as well as between daytime and nighttime, due to the increasing use of cooling equipment. This brings about a decrease in power generating facilities' operating rates or annual load factors. In the Kyushu Electric service area, the gap between the monthly maximum power in mid-summer and winter reached 5,520,000 kW in 1998, a great increase compared to the 3,350,000 kW recorded in 1983. Further, the gap between daily maximum power demand (daytime) and its minimum power demand (nighttime) was 8,660,000 kW in 1998, and this disparity is widening year by year. This means that about 10 power generating units (700,000 kW per power generating unit in average) in full operation during the day must be either stopped at midnight or go into minimum operation, resulting in an inefficient availability of power generating facilities. In response to these problems, power companies are tackling the development of novel systems or devices that enable electricity storage by utilizing nighttime surplus power and discharging this power during the daytime. The battery-applied power storage system, which contributes to load leveling, is one effective solution to improve the availability of power generating facilities. Currently, sodium–sulfur batteries, Zn–bromine batteries and redox-flow batteries that can be used in power storage systems are being developed in Japan. The authors focused on Li-ion batteries, commonly used in mobile phones and which feature a high specific energy at atmospheric temperatures, and made efforts to create a large capacity, large-scale battery for power storage use. In most cases, Li-ion batteries employ cobalt as the cathode material; however, cobalt is not suitable for large-scale batteries from a viewpoint of resource availability and cost. For this reason we decided to employ manganese materials, which are readily available and safe to use. Finally, a foreign element, doped spinel Li–manganese oxide, which has a long lifecycle and high temperature characteristics, was applied to a 270 Wh cell to serve as the cathode material. In this way the 1.1 kW module battery composed of four cells in a series was created.

In this research, we first produced 270 Wh cell prototypes in which the foreign element, doped spinel Li–manganese oxide, was used for the cathode. The cell characteristics were examined in a lifecycle test and specific power test. A 16 kWh battery pack composed of 15 module batteries was also evaluated. After developing the Li-ion battery pack, research was also made into how the proposed 16 kWh power storage system, which comprises an inverter, a battery

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protection system and the battery pack, can perform in practical situations.

2. Experimental

2.1. 270 Wh cell

We produced the cell prototype, featuring a rectangular shape and a layered quadrilateral cathode and anode with the rated capacity of 270 Wh. Li–manganese oxide was used for the cathode, and graphite for the anode. EC, DMC, and $LiPF_6$ were used for the prototype's electrolyte. A cell cycle test was conducted under the conditions whereby charging was carried out at constant current and constant voltage values, and discharging was the rated 70%. Next, we measured the individual characteristics of both the cell current and the voltage of 40, 60, and 80% DOD at the atmospheric temperature. From this, the cell's specific power was estimated.

2.2. 16 kWh battery pack

A 16 kWh battery pack comprises 60 units of 270 Wh cell prototypes, and was developed specifically to achieve a longer lifecycle. After all prototypes were fully charged at the constant current and voltage values, they were discharged to 3.1 V. Then the battery pack capacity was measured. We repeated this procedure three times to achieve the average capacity value, thus obtaining the equivalent capacity value of the cell prototypes. Next, we formed the 1.1 kWh module battery in which four cells were connected in a series, and created a single 16 kWh battery pack from a series of 15 of these module batteries. The charging and discharging efficiency of the battery pack was measured in the experiment.

2.3. Battery protection system

As well as producing cell prototypes in the experiment, we incorporated a battery protection system into the proposed power storage system to promote even voltage values and thus prevent over-charging and over-discharging due to cell capacity unbalancing. This system was integrated into each module battery. We evaluated the performance of this battery protection system under the conditions whereby the charging capacity of only one cell in the four-cell series, comprising a module battery, was decreased by 10%. This charging test was carried out at constant current and constant voltage values. Our final focus was to make each cell voltage almost equivalent.

2.4. 16 kWh power storage system

After the above experiments, we formed a 16 kWh power storage system from the battery protection system, inverter, and 16 kWh battery pack, and conducted several experiments as follows.

2.4.1. Total system efficiency

Our ultimate target was to improve the system efficiency of the proposed system. To evaluate its performance, we calculated total system efficiency by calculating the ratio of output kWh to input kWh when the proposed system was in normal operation, by connecting a wattmeter to both the system's input side (power system side) and its output side (load side).

2.4.2. Response to load fluctuation

The other point examined was how well the proposed system responded to load fluctuation. We decided to examine the system's response ability during two typical operation modes: self-sustaining operation where the system was isolated from the power system; and system interconnection, where the system was linked to the power system.

2.4.2.1. Self-sustaining operation mode. The system operation mode was perennially set in a forced discharging condition and the primary-side power source was then cut. The system's response to load current and cell current was examined under varied conditions, including a no-load condition, stepped load increase/decrease, and so on.

2.4.2.2. System interconnection mode. The system was linked to the power system, and the same experiments were conducted as those in the self-sustaining operation mode. However, during the period in which cell current followed load fluctuation, transient current flowed from the power system to the power storage system. Therefore, we examined not only the response on the load current and cell current, but also its transient response on power system current.

3. Results and discussion

3.1. 270 Wh cell

The result of a 270 Wh cell cycle test is shown in Fig. 1. The deterioration rate was 0.02% per cycle, and an estimated life of about 3500 cycles under the testing condition was achieved. An equivalent life span was confirmed for the

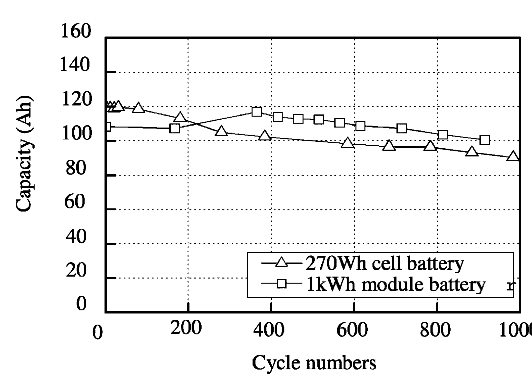

Fig. 1. Cycle performance.

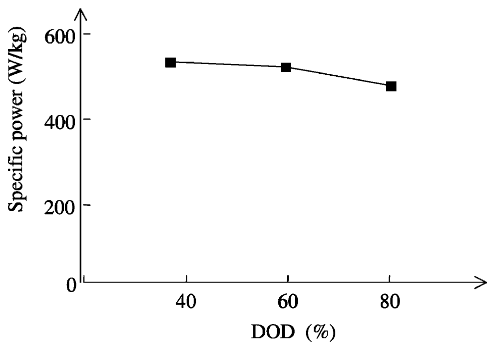

Fig. 2. Specific power characteristics of 270 Wh cell.

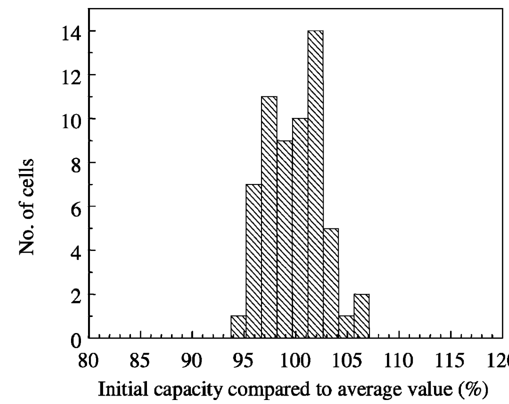

Fig. 3. Battery capacity of each 270 Wh cell.

1.1 kWh module battery. An improved 270 Wh cell prototype now under development shows a deterioration rate of 0.015% per cycle, showing a longer life due to upgraded operation cycles. Fig. 2 illustrates the cell's specific power characteristics. The specific power is about 460 W/kg under the conditions of the rated 80% DOD. This value proves that the developed cell has satisfactory output characteristics, suitable for power storage use and for electric vehicles. The foreign element, doped spinel Li–manganese oxide used for the cathode, has a 3D channel structure, resulting in a high output. Also, the oxygen shortage was reduced and the dissolution of Mn^{2+} could be reduced. These factors contribute to prolonging the cell's lifecycle [1]. In addition, it is considered that a factor for prolonging the cell's lifecycle may depend on individual raw materials such as Mn_3O_4 and γ-MnOOH [2]. Table 1 shows the 1.1 kWh module battery

Table 1
11 kWh module battery specifications

Weight	12.0 kg
Size	120 mm (*W*) × 270 mm (*L*) × 179 mm (*H*)
Nominal voltage	14.8 V
Nominal capacity	73 Ah
Specific energy	150 Wh/kg (maximum)
Specific energy	290 Wh/l (maximum)

specifications. A maximum energy capacity of 1.76 kWh and specific energy of 150 Wh/kg and 290 Wh/l were revealed through the experiment.

3.2. 16 kWh battery pack

Fig. 3 shows the battery capacity distribution of each 270 Wh cell on 60 prototype units. Each cell's initial capacity was 5% greater than or below the average value, and this finding confirmed that there were no problems in producing the battery pack prototype and the module battery. The electrical energy efficiency of the battery pack, without the energy expended on components such as cooling fans, was 97.3%. It reveals the high efficiency of Li-ion batteries.

3.3. Battery protection system

The battery protection system continuously supervises battery data such as voltage, current and temperature. In the case of over-charging, over-discharging and over-current output/input, the power storage system stops instantly to protect the batteries. The system also functions to keep each cell's charging state unified. Fig. 4 shows the effect of

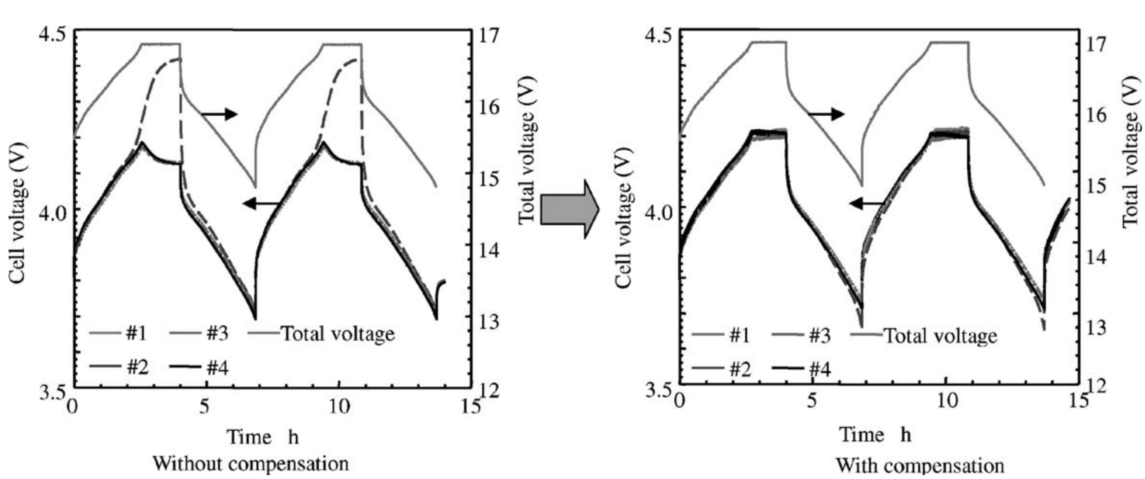

Fig. 4. Effect of cell balancing compensation (under the condition that only one cell's charging capacity is decreased by 10%).

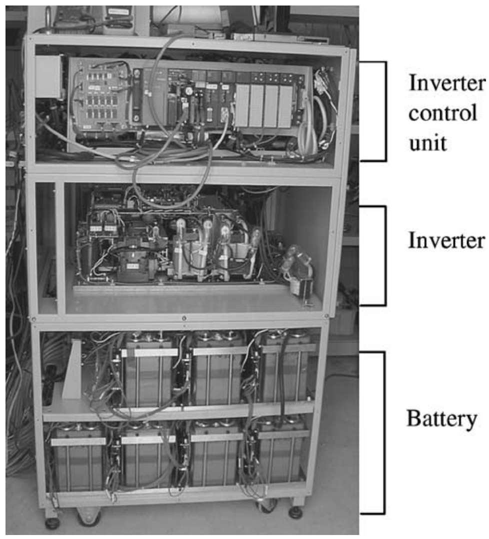

Fig. 5. 16 kWh power storage system.

cell balancing compensation. Compared to the case where cell balancing compensation is not used, the proposed power storage system is connected to this system, and voltage imbalance in the cells can be compensated to keep voltage values even. Thus, balanced battery capacity is achieved, contributing to a longer battery life and easier safety upgrading.

3.4. 16 kWh power storage system

3.4.1. Total system efficiency

Fig. 5 shows the 16 kWh power storage system, composed of the battery protection system, inverter and 16 kWh battery pack. The total system efficiency obtained in the experiment was about 78%. The inverter used in the experiment was created from a remodeled general purpose inverter, which had a slightly lower efficiency rate of 91%. In the future, we aim to tackle the development of an improved inverter exclusive for the proposed power storage system. We will also aim for a total system efficiency rate of 85% to benefit from low power loss in the battery protection system.

3.4.2. Response to load fluctuation

3.4.2.1. Self-sustaining operation mode. The response time during load fluctuation was within 200 ms, and there were no problems in system performance.

3.4.2.2. System interconnection mode. Fig. 6 shows the response characteristics during load fluctuation in the case where the proposed system is linked to a power system. A single scale on the horizontal axis indicates a unit of 50 ms. It was seen that the response time was within 200 ms as well. Compared to the reference value of 500 ms or less adopted in Japan, this value was no problem.

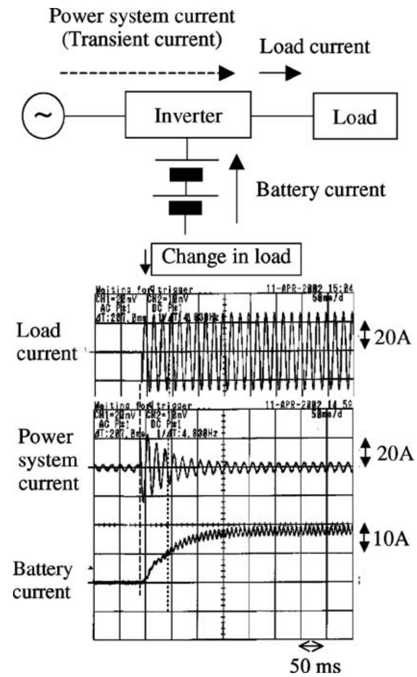

Fig. 6. Response characteristics during load fluctuation.

Through the experiment results and evaluations described above, we confirmed that the proposed 16 kWh power storage system prototype applying Li-ion batteries performs satisfactorily and without any issues of concern, and displays a superior response to load and inverter control.

4. Conclusions

A 16 kWh power storage system that operates on Li-ion batteries has been created. The system comprises an inverter, a battery protection system, and a Li-ion battery pack. Four cells, each with a capacity of 270 Wh, are connected in a series to form a single 1.1 kWh module battery. The battery pack is composed of a series of 15 such module batteries. A 270 Wh cell, in which A Li–manganese oxide is used for the cathode and graphite for the anode, has a long life of 3500 lifecycles at the rated 70% DOD. A full 1.1 kWh module battery has a maximum energy capacity of 1.76 Wh, a specific energy of 150 Wh/kg, and a specific energy of 290 Wh/l, displaying superior specific power characteristics. A battery protection system that enables the voltage value of each cell to be kept unified, which is necessary to prolong the life and improve the safety of battery packs, was also produced in the experiment. This protection system succeeded in keeping the voltage of each cell almost equivalent. Our research and various related experiments have revealed that the proposed power storage system applying Li-ion batteries has sufficiently cleared our initial targets in terms of basic performance, and shows an excellent response to load. Our future targets will focus on further upgrading system efficiency by reducing power loss in the inverter and battery protection system.

Acknowledgements

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